A STUDY AND DEVELOPMENT OF OPTICAL DEVICES TO AID PERSONS WITH SUBNORMAL VISION

FINAL REPORT

of the

DARTMOUTH EYE INSTITUTE

DARTMOUTH MEDICAL SCHOOL

HANOVER, NEW HAMPSHIRE

Report Serial No.: CSD 47-14


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COMMITTEE ON SENSORY DEVICES

of the

Division of Engineering and Industrial Research

and the

Division of Medical Sciences

NATIONAL RESEARCH COUNCIL

Final Report

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[illegible]

The Dartmouth Eye Institute

Dartmouth Medical School

Hanover, New Hampshire

Under Contract

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Made by

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Hanover, New Hampshire

Under Contract

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Serial: CSD-47-14 June 30th 1947

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OPTICAL DEVICES FOR THE AID OF PERSONS WITH SUBNORMAL VISION.*

DARTMOUTH EYE INSTITUTE

HANOVER, NEW HAMPSHIRE

FOREWORD

Dr. Gabriel Farrell, of the Perkins Institution for the Blind, in Watertown, Massachusetts, was primarily responsible for initiating this project, and it was he who interested the Committee on Sensory Devices of the Office of Scientific Research and Development in sponsoring the project. As a consequence, the particular direction that the study has taken has been in accord with his point of view. Both he and the Committee had in mind the possibility of aiding not only returning servicemen who have been partially blinded as a result of the war, but also the many children in this country whose education is said to be handicapped by the lack of standard texts printed in large type.

The project separated itself into two phases:

(1) A comprehensive survey was to be made of the existing optical devices for the aid of subnormal vision. Depending upon the conclusions of that survey,

(2) Steps were to be taken to develop an improved device that might be a better aid than those now available.

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*This report covers the period from June 15, 1945 to June 30, 1947. This work, originally an O.S.R.D. project, OEMsr-1495, was transferred to the National Academy of Sciences on October 1, 1945, as Project VAM-21223, Subcontract 20.

It was thought that out of the experience gained in optical science during the war, a new approach could be made in the design of such a device.

The report of the survey of optical aids for subnormal vision was prepared by Mr. Vincent J. Ellerbrock, who conducted the first phase of the project. This report was submitted to Dr. George W. Corner, Chairman of the Committee on Sensory Devices in December, 1945, and it was subsequently accepted by the Committee and by the headquarters of the O.S.R.D. as the final report requirements for the O.S.R.D. supervision of the project.

The present report is concerned primarily with the second phase of the project.

The essential conclusions of the survey pertinent to this second phase were:

(a) The available devices have proved unsatisfactory, not only because of physical and optical limitations, but also because of the psychological and educational factors involved in their use.

(b) Of the important feasible devices, it was believed that significant improvement could probably be made only in magnifying lenses and in optical projection instruments.

This report concerns attempts to improve magnifying lens devices.

THE PROBLEM

The functional specifications for the magnifying device were clearly stated before this phase of the project was undertaken. The requirements were:

(1) That the device magnify print the size of that of the ordinary textbook (9 or 10 point) to the size of 18 to 24 point. This means a magnification of at least two times.

(2) That the optical field of the device be such as to include the entire width of the print, that is, 4-1/2 inches (12 cms).

(3) That the device should be such that it can be used under ordinary classroom or library conditions of space and lighting.

Telescopic lenses or spectacles without excessive weight could not meet these specifications. In order to obtain sufficiently high magnification, the size of the field was greatly restricted. When the field was widened, the telescopic unit immediately became too heavy. Moreover, the coordinated head and eye movements that are necessary with these devices of high magnification prove generally tiring.

MAGNIFYING LENSES

The essential problem is to increase the size of the image on the retina of the eye. This increase can be obtained in two ways: First, by bringing the reading material nearer to

the eyes, and secondly, by an enlargement obtained by a magnifying system before the eyes.

Referring to Figure 1, the angular magnification of the image to an object, due to a magnifying lens (neglecting the thickness of the lens) is given by

$$M = \frac{1}{1 - \frac{h}{p}\left(2 - \frac{p - h}{f}\right)}$$

where h is the distance of the lens from the eye, p the distance of the object plane from the eye, and f the focal length of the lens. If the image is placed at a considerable distance from the eye, by making $f \longrightarrow (p - h)$, $M = \frac{p}{p - h} = \frac{p}{f} = \frac{f + h}{f}$. These formulae state only the relative angular magnification of the image of an object at the distance p from the eye.

From the point of view of the size of the retinal image of printed matter, it is necessary to specify some standard type sizes at a particular distance from the eye. This distance is sometimes referred to as the "distance of distinct vision."*
If this distance is designated as p_o, the magnification of the image on the retina for print at this distance will be $M_o = \frac{p_o}{f}$, (this of course implies that $f = p - h$, and, therefore, the image is at a considerable distance from the eye).

The diameter of the lens obviously must be larger the greater the distance of the lens from the eye--<u>if</u> the same field size is to be included.

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*Introduction to the Theory of Spectacles, O. Henker. Eng. trans. Jena School of Optics, 1924, pp. 182-184.

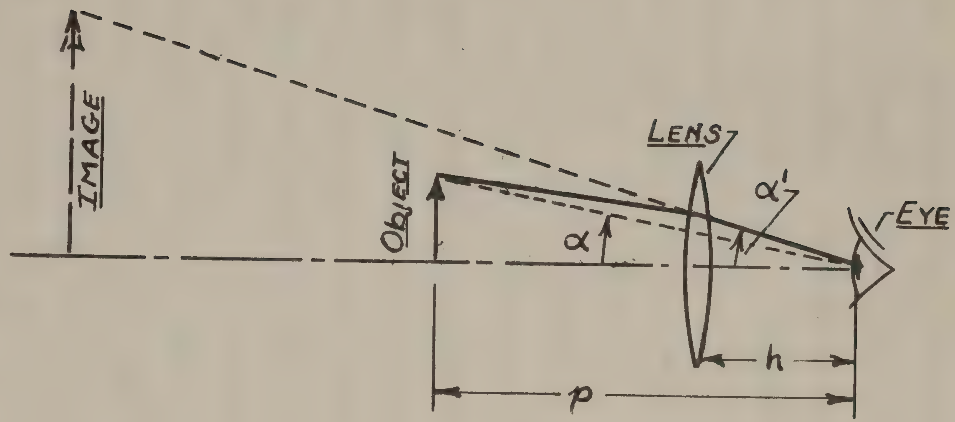


Figure 1. General scheme of a magnifying lens.

In any system that magnifies a page of print, so that the image is greatly enlarged, the eyes will have to make large excursions in reading a line across the page. There is a limiting angle for these eye movement, beyond which head movements must also occur if the line is to be read. The fatiguing aspects of this phase of the enlargement problem must be taken into account. Usually textbook print at a reading distance of 14" involves an eye excusrion of 15° to 20°. If movements much greater than this are required, head movements also come into play. An angular magnification of 2X for print at the same visual distance would undoubtedly require some head movements.

Because of the problems of the refractive corrections for near vision in presbyopic eyes, or in the cases of aphakia (especially when congenital cataract has been removed), it was believed an advantage to have the image of the print as seen through the magnifier at a distance of 1 to 2 meters from the eye. Some gain in magnification is also obtained from such a procedure. In magnifying devices of this type, only one eye can be used if aberrations are to be avoided. There is a tendency, however, for observers to converge their two eyes toward the book upon first looking into the magnifier. With this convergence, especially in normal subjects, there is also an accommodation, and then the image seen through the lens will appear blurred. The accommodation must be relaxed before the print appears clear. In general this is not an obstacle to the use of the lens, for a large proportion of the subjects needing such a magnifier will

either have no accommodation, or the other eye will have much poorer vision. Further, an occluder can be used before one eye, if necessary.

The essential problem involved--as in most optical systems--is to eliminate aberrations which destroy definition of the images or introduce distortions of the images toward the edges of the fields, with as simple a design as possible. These aberrations usually increase very rapidly toward the edge of the field, are worse the larger the size of the field, and the higher the magnification. At the present time lens systems with high magnifications of 2X or more cannot be obtained with fields as large as the width of the print of a book. It is also possible only to design a lens to meet the specifications for use with one eye, that is, not a binocular instrument.

During the war, the technique of grinding and of molding aspheric surfaces became greatly improved, so that there was an opportunity to reduce the distortion and loss of definition of the image by the use of such optical surfaces. The Institute of Optics at the University of Rochester, under the direction of Dr. Brian O'Brien, has been foremost in this work. It was natural to look to that institution for cooperation in making available experimental models of magnifiers.

INSTRUMENTATION

I.

The first approach to the problem was to construct an experimental instrument which would meet the specifications and

Figure 2

Figure 3

Figure 4

Figure 5

Rochester Experimental Model

Because of the cost of manufacture of an experimental model of this lens, but more because of the fact that the University of Rochester also developed a simpler design about the same time, this lens was not constructed.

III.

The simplified lens developed by the Institute of Optics, based on a smaller model constructed during the war for another purpose, was a sphero-aspherical unit. This lens, while designed to be used with a field-flattening plate on the reading material, incorporated the same optical features as the lens described in (II) above, but it was less expensive to manufacture. The unit consisted of a plano-spherical lens and a plano-aspheric plate, the two plano surfaces being placed in contact. No attempt to correct chromatic aberrations was made. A brief description is given in Appendix B, and the resulting measurements of its optical characteristics are given in Appendix C.

This lens was mounted in the head piece of a magnifying lens unit manufactured by the Stanley Electric Tool Company in New Britain, Connecticut, with a built-in fluorescent illuminating system. This optical arrangement was then attached to a special easel (built in the Dartmouth Eye Institute shop) for supporting the reading material. The field-flattening lens was not used. The advantages of allowing the reader to have access to the book for adjustment, turning of pages, and following the page with a finger, were greater than the added image improvement. Figure 6 is a photograph of this pilot model device.

Figure 6. Photograph of a pilot model magnifier with sphero-aspheric lens.

This arrangement permitted an actual angular magnification of 2.0 times, or relative to print at 40 cms. of 2.6 times. Functional tests with this model on subjects who had impaired vision are described in Appendix F.

TESTS

The Rochester experimental magnifier model was tested at the Perkins Institution for the Blind, in Watertown, Massachusetts, and also in the sight-saving classes in the public school in Watertown. In all, about seventy subjects were so tested; cf. Appendix E.

The simplified sphero-aspheric lens with reading stand (pilot model) was tested in sight-saving classes of the 7th and 8th grades of the New York City public schools. Thirty-five students were tested; cf. Appendix F.

The purpose of these tests was to

(1) Determine what would be the range of visual acuities for which the magnifier would be useful;

(2) Ascertain the reaction of persons with subnormal vision to the magnifier; and

(3) Ascertain the larger problems involved in aiding subnormal vision in reading.

(1) The magnification of 2.4 times relative to print at 40 cms. (16") can be of aid only to those subjects whose visual acuity is not worse than 20/150. Persons with visual acuity of 20/200 or poorer are considered blind legally. Whether subjects with visual acuities of from 20/150 to 20/200 could read print

through the magnifier was unpredictable, for considerable variation was found. It would seem, therefore, that somewhat higher magnifications would be desirable.

(2) There is considerable variability in the degree of visual aid obtained with the magnifier for different types of eye defects. It therefore would appear that no one magnifier is going to be satisfactory for all subjects even though they have the same reduced acuity. Some subjects wanted more light on the page, others less.

(3) The general comments of supervisors of the subjects were, on the whole, encouraging. One expressed the opinion that the lens' being a monocular instead of a binocular device, reduced the practicability of the instrument. Only one teacher of a sight-saving class expressed the opinion that, even if excellent optically, the instrument was of no practical value. Others expressed the desire to have at least one in the classroom or library for use and evaluation. Even in classes where many of the texts were printed in large type, it was thought that the magnifier would be of value for collateral reading.

IV.

On the basis of the results obtained from the study of the above magnifier, it was decided

(a) To construct four of the 2X magnifiers, with a new design of lens support and book easel.

(b) With cooperation of the Institute of Optics at Rochester, to construct another sphero-aspheric lens of higher power so as to obtain a 2.5X magnification. This lens was to be

mounted in a unit similar to that used for the 2X magnifiers above.

Figures 7 and 8 show several photographs of the device as finally constructed.

In the meantime the Committee on Sensory Devices set up a sub-contract with the Perkins Institution for the Blind and the Harvard University Educational Clinic jointly, to study these devices (and others) from the point of view of the psychological and educational problems involved in their use. This was believed to be a necessary part of the larger program, and one outside the activities of the Dartmouth Eye Institute. For this project, four 2X magnifiers were shipped to Perkins Institution on February 7, 1947, and two 2.5X magnifiers were taken by Dr. Farrell of Perkins on February 14, 1947.

V.

The greater increase in the angular size of the print (and therefore in the size of the image on the retina) comes through moving the print nearer the eye. Beyond the near point of accommodation, however, the print will become increasingly blurred. By inserting a convex lens of suitable power before the eye the print can be made clear, and this procedure also somewhat increases the angular size of the print. It was suggested, therefore, that a high relative magnification could be obtained for a person with low visual acuity, by having him wear a 12 or 14 diopter lens before one eye, and hold the print about 10 cms. from the eye. Obviously the field would be small, and the print would have to

Figure 7. Photograph of final 2X magnifying device developed in the project.

Figure 8. Other photographs of the magnifier and its uses.

be moved back and forth across the field of view for reading. This might not be useful for continuous reading, but would be helpful for short periods of time.

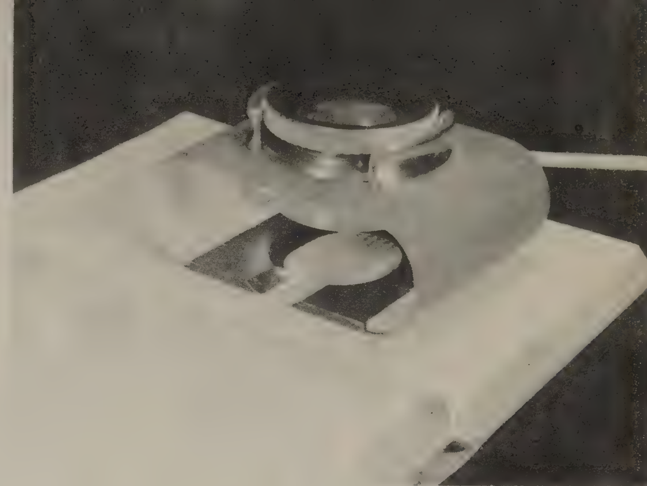
Two pairs of spectacles were made up, in which one eyewire contained a 12 (or 14) diopter (aphakic) lens, and the other a frosted glass. These spectacles had a so-called X-nosepiece which permits their being inverted if the other eye is to be used. Such a device would give an increased angular size of the print compared to that of 40 cms. of approximately 5X.

These spectacles were mailed to Perkins Institution March 18th, for specific use by a former army captain who lost central vision due to malnutrition in a Japanese prison camp.

VI.

From the study described in the earlier parts of this report, it is clear that it is difficult to obtain a simple optical magnifier which will give a 4-1/2" field with a higher magnification than 2 to 3 times and still provide good definition of the image. Such magnifiers are restricted to subjects whose vision is not poorer than 20/200.

It was believed to be within the scope of this project to study briefly the problem of obtaining higher magnifications with somewhat restricted field. Dr. Robert E. Hopkins at the Institute of Optics at the University of Rochester was also interested in this problem. As a result he designed several such magnifiers. Figure 9 shows photographs of one which has a 4X magnification but which takes in only about a 2" field. The lens is mounted in



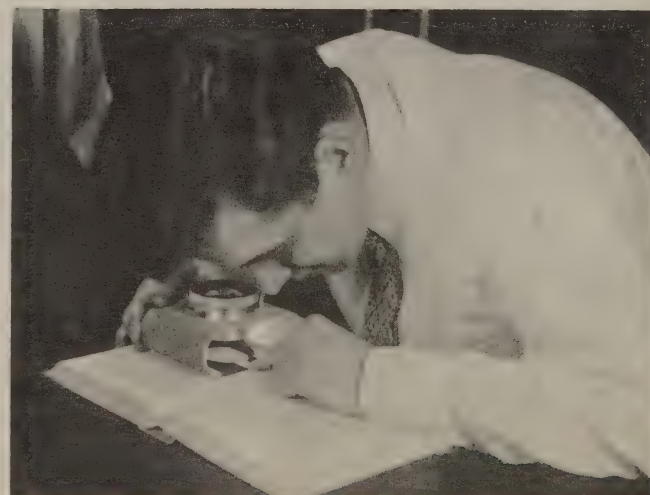


Figure 9. A 4X magnifier with restricted field. Design and construction by the Institute of Optics, University of Rochester.

a suitable housing with built-in illumination. The housing rests directly on the printed page. For best results the eye must be used close to the lens. Here it will be necessary to move the lens unit and head across the print. To what extent this type of magnifier will have use can be determined only by such a group as that included in the Perkins-Harvard project.

This magnifier was sent to Perkins on May 19, 1947.

This report was prepared by
Kenneth N. Ogle, supervisor
of the project.

A P P E N D I X E S

APPENDIX A

Experimental Visual Aid Reading Glass*

Institute of Optics
University of Rochester

A special reading glass has been designed and constructed for experimental use as an aid to persons with defective vision. In order to produce a sample at an early date, the design is simply a large-size version of a special magnifier designed for another application in much smaller size and shorter focal length. Partly because of this the magnifier described below is heavier and more expensive than necessary for the present application. However, its performance is good and should permit appraising the relative values of large field, high quality of image, and large freedom of eye point, as applied.

The optical system is shown in Figure 1. It consists of two cemented doublets, a molded glass aspheric plate, and a plano-concave field-flattening lens which also serves as a pressure plate to be held against the book or other reading matter.

The lens system is designed exclusively as a monocular magnifier, and should not be used for binocular vision. The nature of the distortion correction by means of the aspheric plate is such as to require this restriction. As a practical matter this restriction will be of little consequence in most defective vision cases.

The photographs, Figures 2-5 inclusive in the main body of the report, show the magnifier mounted for preliminary experiments only. It should be emphasized that this mount will require marked modification to provide reading comfort, since in its present form it is simply placed upon the page to be read, and the observer must look straight down (subject only to slight desk tilt) in using it.

Since the designed field of view is a 7 inch circle made necessary by the initial requirement that the magnifier cover a 5 inch square, the field flattener has been cut in the form of a disc of this diameter with part of two sides cut away, to permit convenient placement on the average book. For convenience in experimental use four black dots of lacquer have been spotted on the under surface of this lower plate in positions corresponding to the corners of the 5 inch square. In final form the lower plate might well be limited in size to just this area, and this should be kept in mind in any exploratory use of the magnifier.

The optical system has a focal length of 178 millimeters. It is designed for an eye relief of about 90 millimeters above

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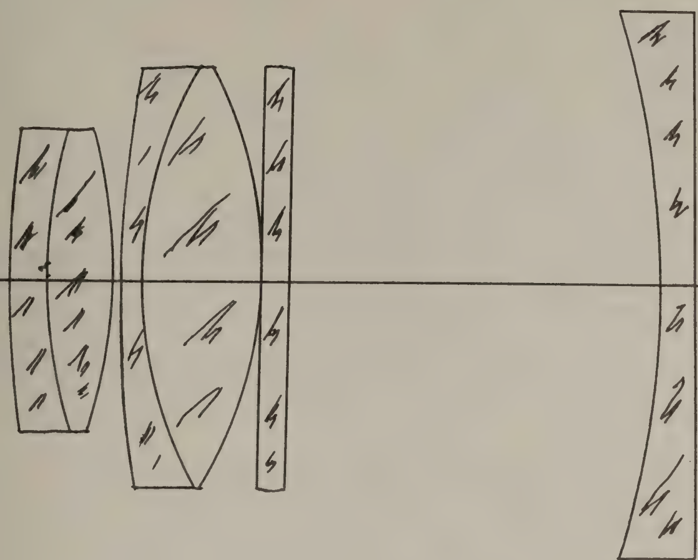
*Copied directly from the memorandum prepared by the Institute of Optics for the instrument.

Figure 1

READING GLASS



ALL DIMENSIONS IN mms

GLASS	N_G	V	t	EDGE DIAMETER	RADIUS	CLEAR APERTURE	SAG-EDGE	SAG-CLEAR
EDF-2	1.689	30.9	10.5	118	624.6			
BSC-1	1.511	63.5	25.4	118	173.6			
			.58		-173.6			
EDF-2	1.689	30.9	10.5	156	624.6			
BSC-1	1.511	63.5	42.0	156	173.6			
			.5		-173.6			
C-2	1.5125	60.5	5.0	156	∞			
					ASPHERIC			
BSC-1	1.511	63.5	8.98	190	-318.0			
					∞			

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the upper surface of the top lens. With the eye in such a position the entire field of view is visible without head movement. The magnification produced by a lens system of this focal length depends somewhat upon the manner of use. In conference with Dr. Kenneth Ogle and Mr. Vincent Ellerbrock it was agreed that the best expression of magnification for the present application would be the ratio of the apparent size of the image with the lens adjusted to require one diopter of accommodation compared to the size of the object at a viewing distance of 16 inches. Under these conditions the present lens system gives a magnification of 2.7 power. A more favorable definition of magnification from the standpoint of the optical system would be the apparent size of an image with lens adjusted so that the image appears to be 16 inches away compared to the size of the objects when viewed at the same distance of 16 inches. On this definition the magnification is 3-1/4 times. However, it is felt that the 2-1/2 diopters accommodation required in this latter case may be uncomfortable for certain users, and that the former condition of use giving 2.7 power magnification is less apt to result in fatigue.

To permit trying the magnifier under a variety of conditions, the lens is provided with a focusing mount, and the side of the base has been drilled and tapped with eight holes, size 10/24. By means of these tapped holes the whole unit may be mounted on an inclined reading frame or other device, and accessories to provide illumination of the page may in turn be mounted on this base.

Illumination of the printed page is important in the use of such a magnifier. At least two small light sources should be placed on either side so that the light enters obliquely through the open spaces between the supporting legs. These should be so placed that no specular reflection from the pressure plate is visible to the observer. Reflection of room lights or windows from the pressure plate or the top surface of the lens system can be very annoying to a user and should be avoided either by shields or by proper location of the magnifier in a reading room.

Since this preliminary model is for exploratory use to provide experience upon which recommendations for design changes can be made, some discussion of limitation and costs is in order. The present expensive and heavy instrument is made necessary by the simultaneous requirements of magnification, size of the field of view covered, image quality at all points in this large field, freedom from distortion so that all printed lines appear quite straight, flatness of field so that no change of accommodation is required from one part of the field to another, and great freedom of eye position to provide corresponding freedom of head movement. Elimination of any one of these requirements will simplify the design. It is probable that magnification and field of view are two requirements which must be adhered to. The rest

may be subject to some modification. For example, the image quality in the present model is sufficient for examination of fine detail by a keen-eyed individual. This quality may be unnecessary for users with defective vision. The elimination of distortion only serves to make the printed lines appear straight. If the user does not object to some pincushion distortion which would result in the top lines within the field of view curving upward at the ends and the bottom lines curving downward at the ends, then the molded glass aspheric plate may be eliminated. Fortunately, due to low cost production methods developed during the war, procurement of this aspheric plate is simple, although it does add a small item of expense. The use of the plano-concave field-flattening lens which also serves as pressure plate may well be unnecessary. Curvature of field in the absence of this plate requires some change in accommodation from center to edge of field (i.e., in scanning a complete line of type across the field) and also results in the slight annoyance of looking at an apparently curved instead of a flat sheet of paper. The cost of this plano-concave plate as compared to a simple piece of plate glass is not a serious item in the total cost of the unit, but nevertheless may be worth considering in mass production. Moreover, the position of the small light sources for illuminating the printed page is more critical because of the curvature of the top surface of this pressure plate, and protection from unwanted reflections as from room lights or windows is slightly more difficult than in the case of a simple piece of plate glass.

The requirement of large eye distance and freedom of eye movement adds very much to the bulk and cost of the unit, providing the rest of the conditions are to be met. The value of such freedom of eye movement can be determined only by trials with a number of users. To simplify such trials three sizes of eye openings are provided for the present model with interchangeable mounts. The largest eye ring is shown in Figures 2 and 3, the medium-size eye ring is shown in place in Figure 4 with the largest and smallest on the table beside the instrument. The smallest eye opening is provided with a rubber eye cup for comfortable positioning of the head, and is shown in place in Figure 5. In preliminary trials with individuals of normal vision accustomed to using optical instruments, the first choice has been the largest eye opening, the second choice, the smallest eye opening with rubber eye cup. An entirely different choice may well be found among individuals with impaired vision, or those unaccustomed to the use of optical devices.

Should the smallest eye opening be found acceptable, the size, bulk, and cost of the unit could be reduced very much without sacrificing field or image quality or any of the other requirements laid down initially. On the other hand if a strong preference is shown for the largest eye opening, then it will be necessary to eliminate some of the other requirements such as image quality if a low cost device is to be achieved.

It is suggested that the above factors be kept in mind in conducting exploratory work with the sample instrument, and that evaluation in terms of them be provided for the benefit of anyone undertaking a productive design.

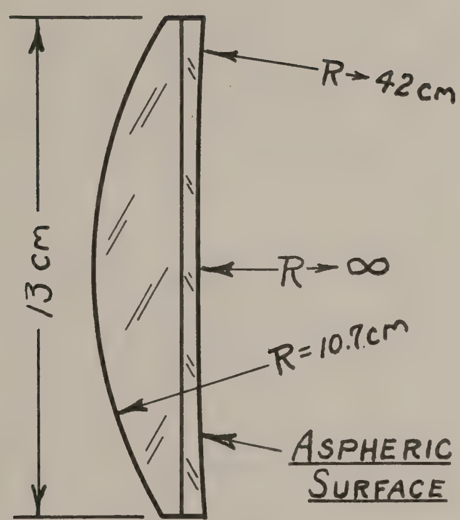


Figure 2. Schematic design of the sphero-aspheric lens.

APPENDIX C

Optical Characteristics of the Magnifiers

The principal optical characteristics of the various magnifiers were measured according to the following scheme:

The magnifying lens was set up over a transparent centimeter scale (illuminated from below), just as the lens would be used in the actual device for subnormal vision (see Figure 3). This scale was scratched on the reverse side of a silvered mirror; a long line was also scratched along the scale intersecting all the division marks. Above the lens and over its center a focusing telescope was supported so that its objective coincided closely with the position that the eye would assume in using the magnifier. The telescope was supported so that it could be rotated about a horizontal axis through its objective and clamped in any position about that axis. The scale seen through the magnifier was set at right angles to this axis. A half-silvered mirror was interposed before the telescope and adjusted so that a meter stick (also at right angles to the transparent scale) could also be seen through the telescope as well as the image of the centimeter scale seen through the magnifier.

After the position of the lens was carefully adjusted so that the telescope was directly over the center of the lens, the telescope was focused for the image of the transparent scale. The meter stick was then adjusted so that it too would be in focus. The distance of the meter stick then measured the distance of the image of the scale from the eye. The distance of the lens could be adjusted then until the image was about one meter from the eye, according to the specifications. With the telescope focused on the scale and the cross-hair seen coinciding with the central division line of the scale, the position of the cross-hair on the meter stick was then read.

The telescope was turned about the axis through a given angle, i.e., until the cross-hair coincided with a given division mark on the transparent scale. The telescope was then focused carefully on the scale division, and then upon the meter stick, and in each case the readings noted. These comparative readings, taken over the extent of the field, gave the data for determining the magnification at any point in the field.

The primary and secondary (tangential and sagittal) power errors were determined by focusing the telescope first on the division mark and then upon the longitudinal line that passes through the scale divisions, and in each case a small glowing filament was moved along the axis of the telescope as reflected by the mirror until it appeared sharply defined. In each case the distance of the lamp from the telescope was then measured. The reciprocal of this distance in meters gave the equivalent dioptric value (diopter) for the image seen through the lens. The difference between the primary and secondary dioptric values

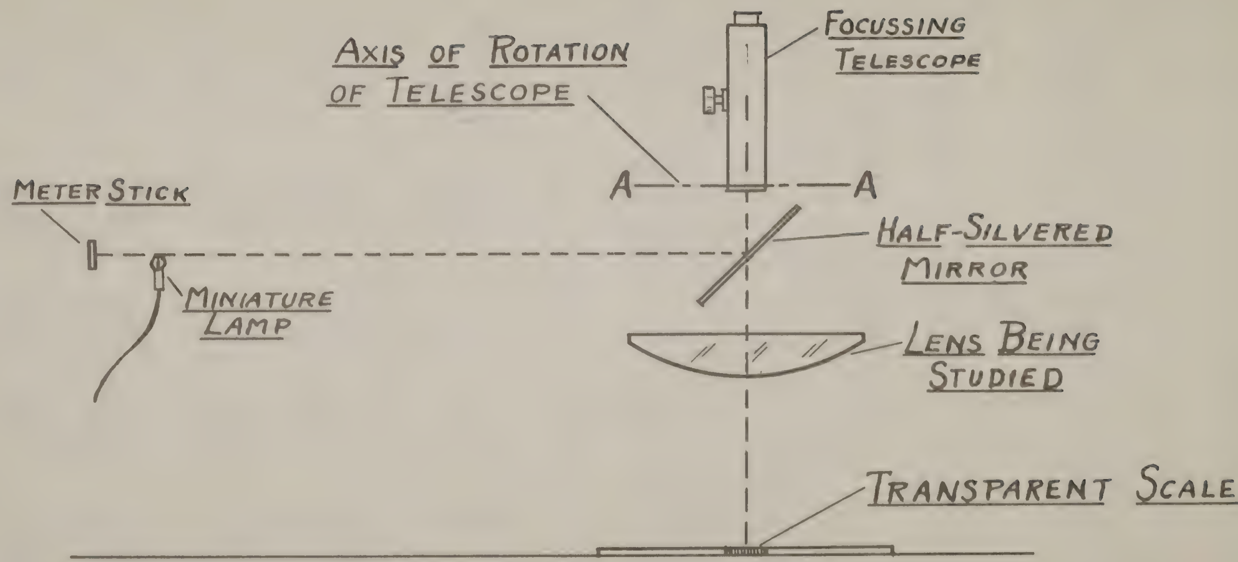


Figure 3. Scheme for mounting apparatus for determining the optical characteristics of the lenses.

measures the astigmatism in terms of diopters referred to the eye.

Chromatic aberration was only qualitatively noted.

Measurements were first made on an ordinary plano-aspherical condensing lens of approximately the same power and dimensions as the Rochester magnifiers.

RESULTS

The results can best be visualized by inspection of the graphical representation of the data.

(A) PLANO-SPHERICAL LENS (CONDENSING LENS)

To help in the comparison of the optical characteristics of the various lens systems examined, the characteristics of the ordinary plano-spherical (condensing) lens of about 5 diopters power and 6 inches in diameter were first determined. The plano surface was set toward the reading material (scale) at a distance of about 13.5 cms. The telescope objective was set about 8 cms. above the spherical surface. The image of the scale was found to be 94.5 cms. from the telescope, an accommodative distance of 1.06 diopters.

The following table gives the results of the measurements:

Scale Setting cms	Meter Stick Reading cms	Magnification	d_p cms	d_q cms	$P=1/d_p$ diopters	$Q=d_q$ diopters
5	152.2	6.14	180.5	-----	0.55	0.2
4	145.2	5.92	126.5	217.5	0.79	0.46
3	138.9	5.80	108.5	130.5	0.92	0.77
2	133.0	5.70	99.5	104.5	1.01	0.96
1	126.1	5.58	96.5	96.5	1.04	1.04
0	121.5	----	94.5	94.5	1.06	1.06
-1	116.0	5.50	96.0	97.5	1.03	1.03
-2	110.5	5.50	100.5	107.5	0.99	0.93
-3	104.9	5.53	111.5	129.5	0.89	0.77
-4	99.0	5.62	129.5	213.5	0.78	0.47
-5	92.9	5.72	159.5	430	0.63	0.23

No data for angles corresponding to scale dimensions beyond 5 cms. could be obtained because of the great loss in definition and greatly increased distortion. The primary and secondary powers are shown graphically in Figure 4. The smallest division on the power axis corresponds to 0.05 diopter, which is below the threshold of coular discrimination. The interrupted lines of short dashes indicate an estimated trend of the data. The aberrations increase very rapidly toward the margins of the field.

The relation between image and object dimensions (and therefore the magnification data) is best visualized by plotting the ratio of I/0, the angular magnification, against the corresponding scale settings of the scale seen through the magnifier. These data are illustrated in Figure 5.

(B) ROCHESTER MAGNIFYING UNIT

This magnifying unit was set up with the telescope objective at that distance corresponding to the eye position with the eye cup in place. It was found that the lens tube had to be screwed down as far as the threads would permit and then the image was 115 cms. from the eye. The measurements are as follows:

Scale Setting cms	Meter Stick Reading cms	Magnification	d_p cms	d_q cms	$P=1/d_p$ diopters	$Q=1/d_q$ diopters
7 cm	166.9 cm	7.10	117.3	74.6	0.85	1.35
6	159.4	7.03	115.3	81.0	0.86	1.23
5	152.3	7.02	115.5	88.2	0.86	1.13
4	145.2	7.00	114.8	95.3	0.86	1.01
3	138.3	7.03	113.9	102.2	0.88	0.98
2	131.2	7.00	115.0	111.2	0.87	0.90
1	124.3	7.10	-----	-----	----	----
0	-----	----	-----	-----	----	----
-1	-----	----	-----	-----	----	----
-2	103.2	7.00	114.0	106.0	0.88	0.94
-3	96.2	7.00	112.5	98.5	0.89	1.01
-4	89.1	7.02	111.7	94.2	0.90	1.06
-5	82.1	7.02	113.4	83.4	0.87	1.20
-6	75.0	7.03	120.9	77.9	0.83	1.28
-7	67.5	7.10	119.7	76.7	0.84	1.30

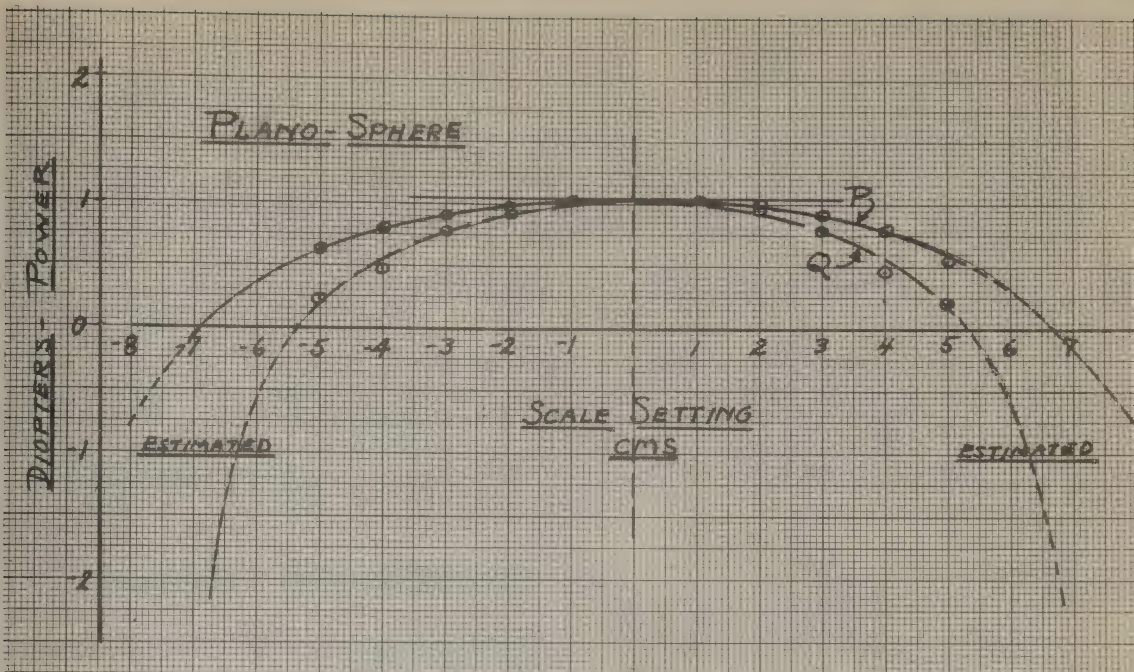


Figure 4. A graph illustrating the primary and secondary power errors for a plano-sphero lens.

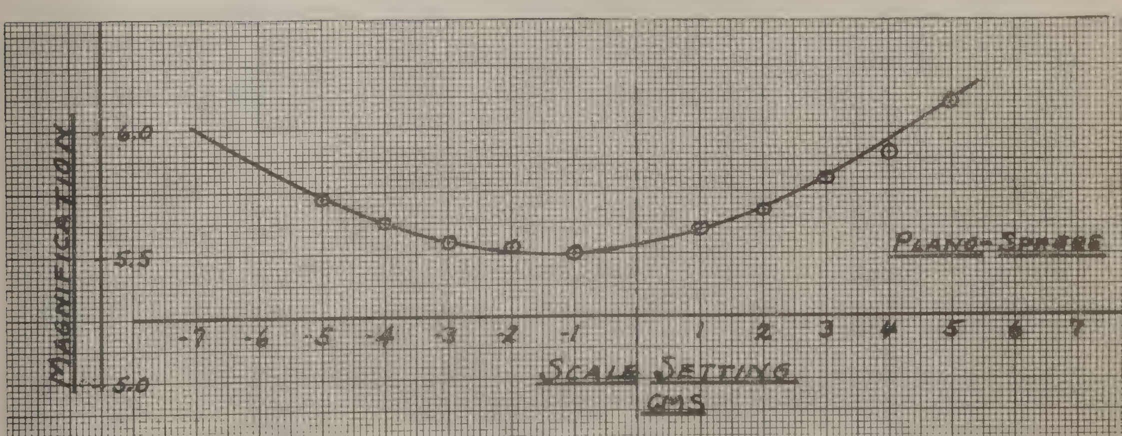


Figure 5. A graph illustrating the magnification characteristics of a plano-sphero lens.

The primary and secondary powers are illustrated in Figure 6. The power error out toward the margin of the field is remarkably low, and the astigmatism at the edge is only 1/2 diopter. The flatness of the P curve is noteworthy.

The chromatic aberration was negligible, though perhaps slightly over-corrected.

The relationship between image and object dimensions as determined by this experimental arrangement is illustrated in Figure 7, where the magnification I/O is plotted. The data show a slight pincushion distortion at the margins of the field. Even this small amount of distortion may mean the telescope was a little too near the ocular surface of the device.

(C) ROCHESTER SPHERO-ASPHERIC LENS

(1) With Field-Flattening Plate Taken from the Rochester Magnifier Unit

This lens, described in Appendix B, was set up so that the image would be at a distance of one meter from the eye. The measurements follow:

Scale Setting	Meter Stick Reading	Magnification	d_p cms	d_q cms	$P=1/d_p$ diopters	$Q=1/d_q$ diopters
7 cm	93.1 cm	6.18	109.4	63.4	0.91	1.58
6	86.4	6.07	109.4	73.4	0.91	1.36
5	80.4	6.08	109.4	77.4	0.91	1.29
4	74.1	6.02	103.4	88.4	0.97	1.13
3	68.1	6.03	103.9	90.4	0.96	1.11
2	62.2	6.10	101.4	91.9	0.99	1.09
1	56.2	6.20	99.4	94.4	1.01	1.06
0	50.0	----	100.0	100.0	1.00	1.00
-1	44.0	6.0	100.0	99.4	1.00	1.01
-2	38.0	6.0	98.4	96.4	1.02	1.04
-3	31.8	6.06	98.4	96.4	1.02	1.04
-4	25.5	6.12	101.0	94.4	0.99	1.06
-5	18.5	6.30	100.9	90.9	0.98	1.10
-6	12.3	6.28	103.9	77.9	0.96	1.28
-7	6.2	6.26	106.9	67.4	0.94	1.48

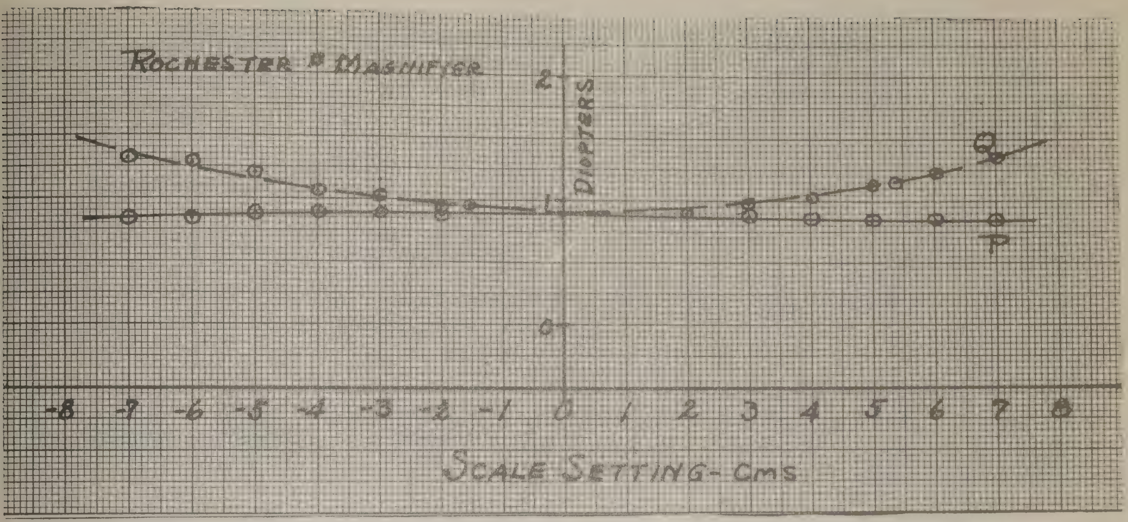


Figure 6. A graph showing the primary and secondary power errors of the Rochester Magnifier.

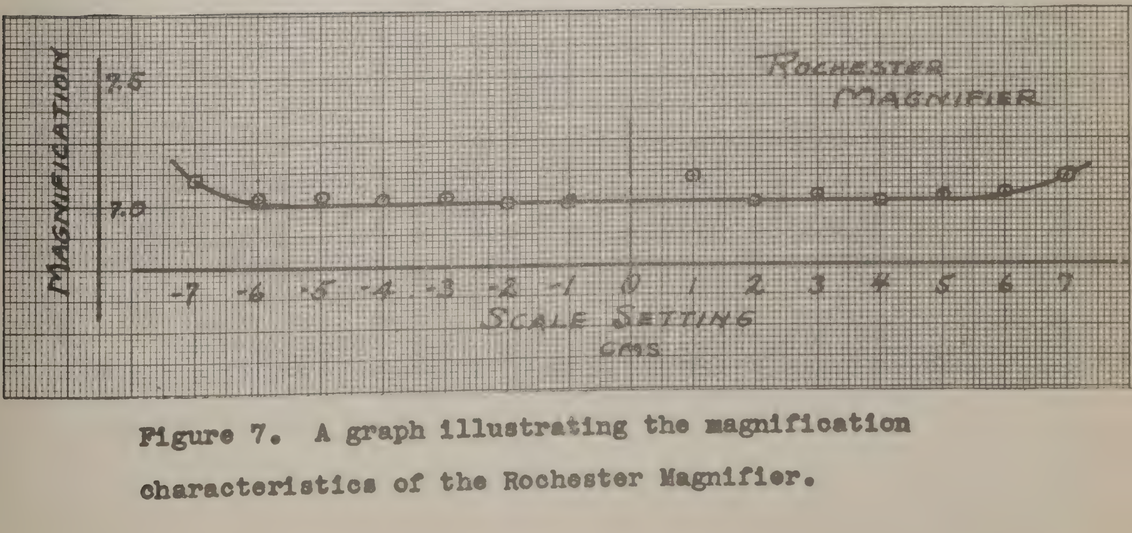


Figure 7. A graph illustrating the magnification characteristics of the Rochester Magnifier.

The primary and secondary conjugate powers, measured from the eye, are graphically illustrated in Figure 8. These powers compare very well with those of the large magnifier (see above section).

The magnification (I/O) of the lens for the set-up is illustrated in Figure 9.

(2) Without Field Flattener

The field-flattening lens in the above setup was removed, and the following measurements obtained.

Scale Setting	Meter Stick Reading	Magnification	d_p cms	d_q cms	$P=1/d_p$ diopters	$Q=1/d_q$ diopters
7	91.1	5.88	102.5	62.0	0.97	1.63
6	85.2	5.86	106.0	74.0	0.94	1.35
5	79.5	5.90	106.0	85.0	0.94	1.18
4	73.5	5.87	102.5	82.0	0.97	1.22
3	67.6	5.86	103.0	98.0	0.97	1.02
2	61.7	5.85	97.0	100.0	1.03	1.00
1	56.0	6.00	100.5	101.0	0.99	0.99
0	50.0	----	100.0	100.0	1.00	1.00
-1	43.9	6.10	104.0	105.0	0.96	0.95
-2	38.0	6.00	104.5	103.0	0.96	0.97
-3	31.8	6.05	104.5	91.5	0.96	1.09
-4	25.7	6.07	104.0	90.8	0.96	1.10
-5	19.5	6.10	106.0	84.3	0.94	1.19
-6	13.0	6.13	109.0	74.0	0.92	1.35
-7	6.4	6.23	108.2	65.5	0.92	1.54

The primary and secondary conjugate powers, measured from the eye position, are graphically illustrated in Figure 10. A comparison of these data with those of the section above shows no influence of the field flattener upon the powers. That might be expected.

The magnification (I/O) characteristic of the lens as set up is illustrated in Figure 11. There is evidence of an asymmetrical distortion, which may or may not be due to some error in mounting the lens. However, there is no marked pincushion distortion.

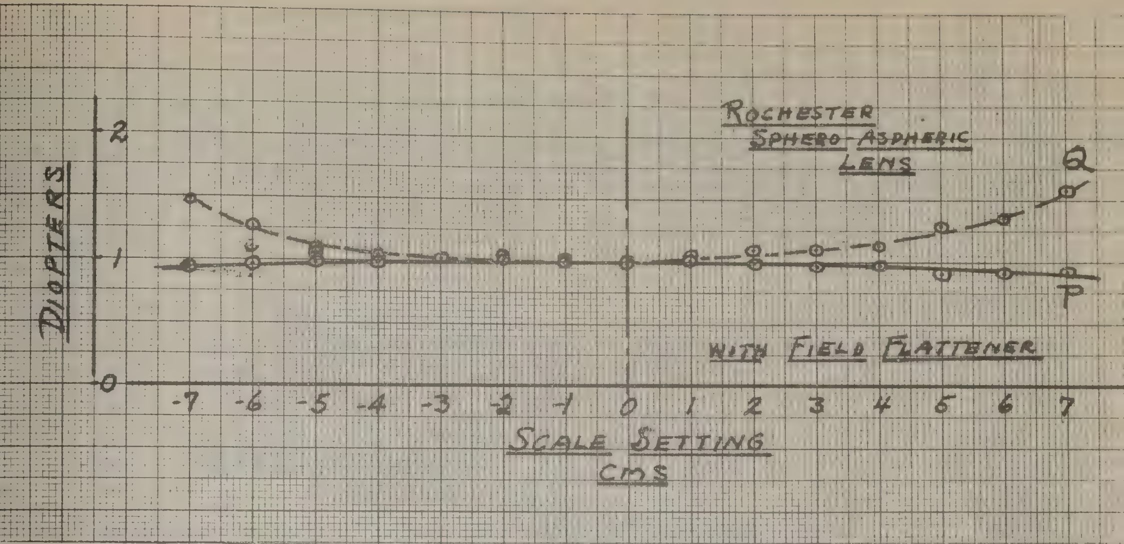


Figure 8. Graph illustrating the primary and secondary power errors of the sphero-aspheric lens with the field-flattening lens.

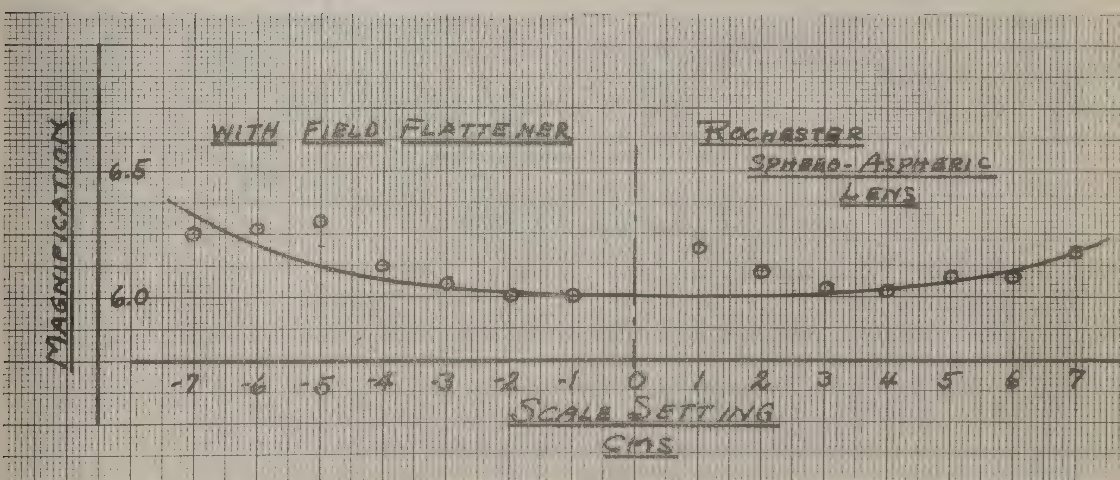


Figure 9. Graph illustrating the magnification characteristics of the sphero-aspheric lens with the field-flattening lens.

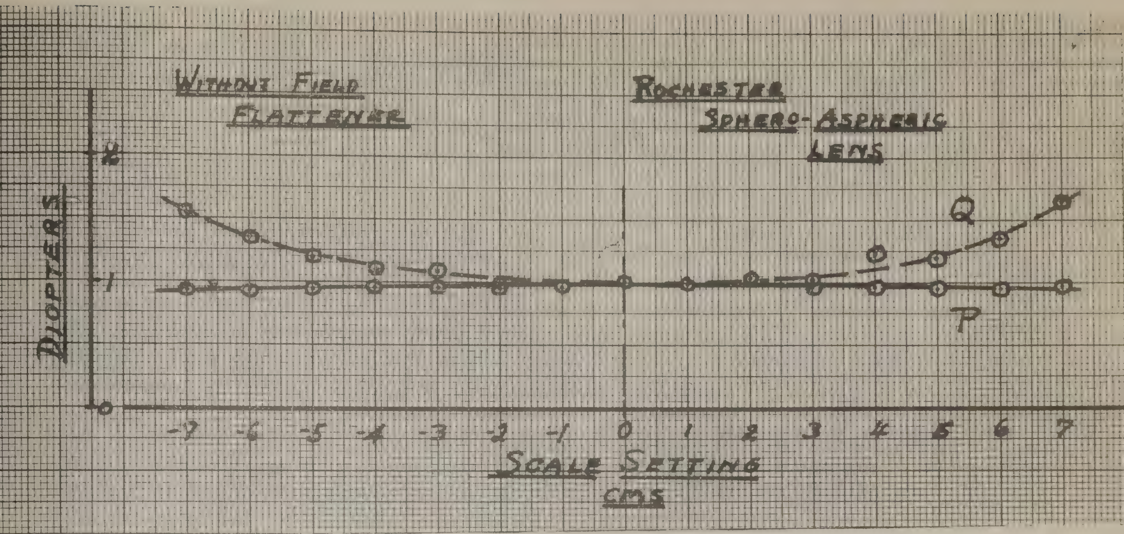


Figure 10. A graph illustrating the primary and secondary power errors for the sphero-aspheric lens alone.

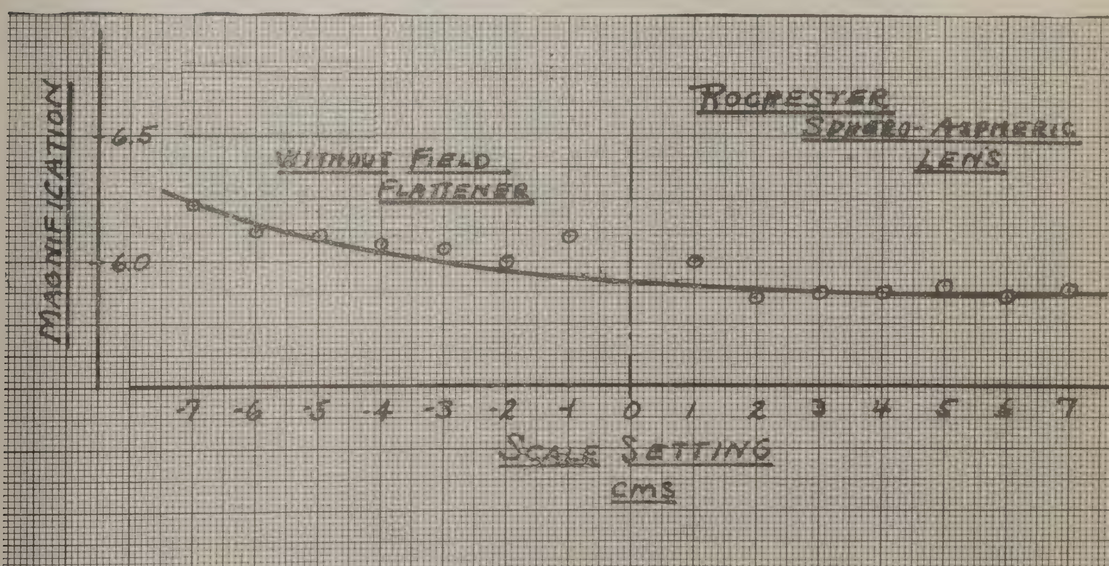


Figure 11. A graph illustrating the magnification characteristics of the sphero-aspheric lens alone.

APPENDIX D

Specifications for a Plano-Aspheric Magnifying Lens

It was felt that one approach would be to design a single lens with a plano surface toward the eye and a convex aspheric surface toward the reading material. The problem was to find a plano-aspheric lens which is distortion-free and for which the dimensions of thickness, distance of lens from object, distance of eye from object, the distance of the image from the eye, the angular magnification, and field size are preassigned.

These calculations were based on a theory of third and fifth order distortion properties developed by Dr. Rudolf Luneburg. The final problem consisted of finding the coefficients of the powers of an equation describing the aspheric curvature., viz.

$$z = a_0x^2 + a_1x^4 + a_2x^6 + a_3x^8.$$

These coefficients were determined by an algebraic method, from recursion type formulae. The mathematical theory is too long to be included in this report, though it is a part of the project.

Several different designs were computed for lenses at different distances from the eye and for different magnifications. Figure 12 gives typical specifications for such a plano-aspheric lens.

When it was learned that the University of Rochester was making a sphero-aspheric lens, the aspheric surface of which was molded from a plate, it was decided to put the above design on file, at least until tests had been made with the Rochester lens. The cost involved in grinding the aspheric surface as a deviation from a spherical surface would be quite expensive.

Equation of aspheric curve:

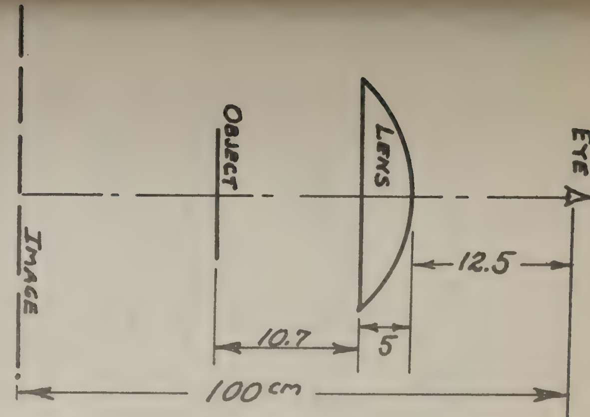
$$z = a_0x^2 + a_1x^4 + a_2x^6 + a_3x^8$$

when x and z are given in decimeters

$a_0 = 0.5736$ $\quad$ $a_2 = 0.4284$

$a_1 = -0.2896$ $\quad$ $a_3 = -0.2430$

x mms	z mms	x mms	z mms
20	2.251	80	32.001
40	8.596	90	39.765
60	18.487	100	46.936



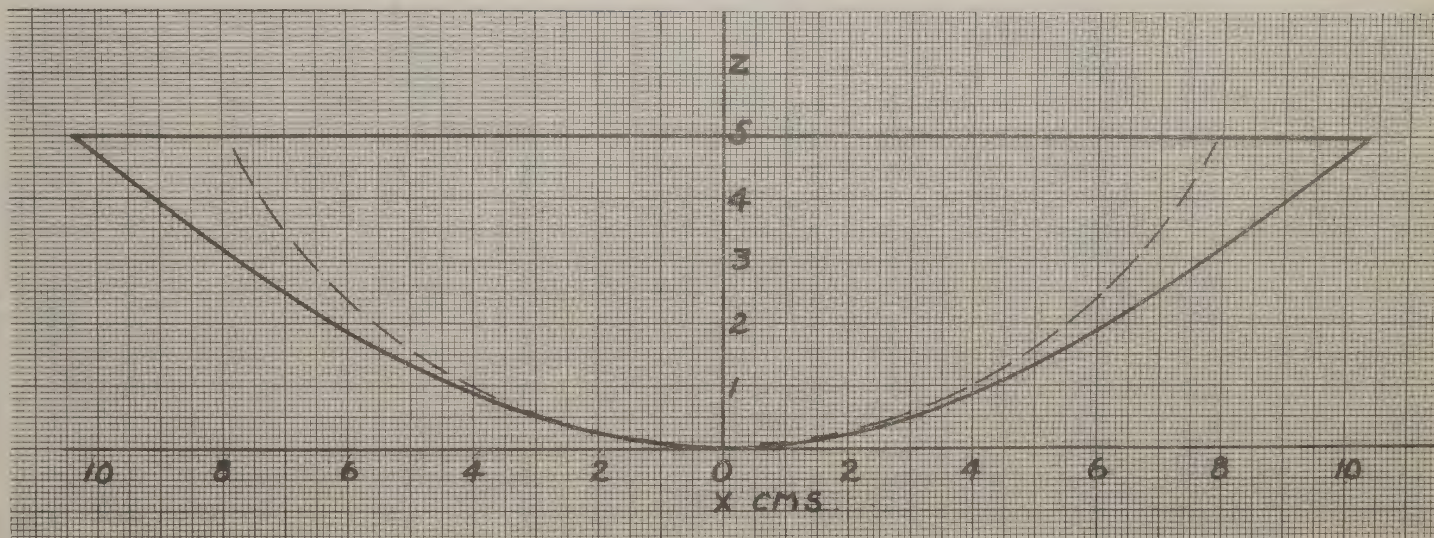


Figure 12. Typical specifications for a plano-aspheric magnifying lens.

APPENDIX E

Functional Tests at Perkins Institution for the Blind using the Rochester Magnifier

About sixty subjects in the Institution for the Blind who had partial vision were used in the tests. The procedure was as follows:

(1) The medical record was examined to ascertain the cause of poor vision, refractive error, the visual acuity as determined by the ophthalmologist in charge, age, etc.

(2) The visual acuity at an intermediate visual distance was determined using a Snellen test card.

(3) The smallest print legible at reading distance of 16", or equivalent at shorter distances using a graded card was determined.

(4) The smallest print that was legible through the magnifier was then determined, with the eye in correct position over the instrument. The type of card used for this test is shown in Figure 13. This card does not represent all that could be desired in a card. The steps are too great, especially in the smaller type, nor are the steps equal. Under the circumstances these were the only type sizes the printer could furnish on short notice.

(5) Comments concerning the device, including illumination, etc., were noted.

The data are graphically represented in a scatter diagram, Figure 14. The conclusions to be drawn from these tests were:

(1) There were too few subjects with vision in the 20/70 - 20/200 range at the Institution for the Blind to make a satisfactory test of the device.

(2) The means of illuminating the test type seen through the magnifier was not satisfactory.

(3) Some subjects at the Institution were too unfamiliar with visual reading for one to estimate easily their ability to read the test card.

(4) Considerable variation in smallest size of print that could be read with the magnifier was found among subjects with the same rated visual acuity. This variation seemed to be associated with the varying nature of the partial blindness. From casual observation the majority of those tested seemed to be cases of congenital cataract. In most cases the cataract had been removed. In a majority of cases there was also some type of nystagmus which lowered their functional visual acuity. These nystagmoid movements also

6 Point

There were once five little children who spent a lot of time teasing for a pony. Their hearts beat as one. they were filled with but a single desire; they thought, chattered, and dreamed of nothing but pony; all five together wished one huge wish continually, till finally and fortunately somebody had a birthday and a pony appeared at the door. The

7½ Point

Once upon a time there was a large rambling farmhouse. It was a beautiful old house, with a lovely front door and beams of strong oak, with a big fireplace in the parlor and a big fireplace in the sitting room. The children thought it was the nicest house in the whole world.

10 Point

Once there was a barn. It was a big red barn and it stood on a hill for all who passed to see. It was much bigger than the little white farmhouse by its side. But it was not nearly so tall as the old elm tree on its other side. Between the little white house

11 Point

There was once a duck who lived in a pen. He had smooth white feathers and orange feet. There was a tub of water in his pen, and he swam in his tub every day. When the children filled his tub with cool, clean water in the morning

12 Point

I lost no time, of course, in telling my mother all that I knew, and perhaps should have told her long before, and we saw ourselves at once in a difficult and dangerous position. Some of the man's money—if he had any—

18 Point

In I got boldly into the apple barrel, and found there was scarce an apple left; but, sitting down there in the dark, what with

24 Point

I could now see that he was a white man like myself, and that his features were even pleasing.

DARTMOUTH EYE INSTITUTE

1946

Figure 13. The test card used in studying the usefulness of the several magnifiers.

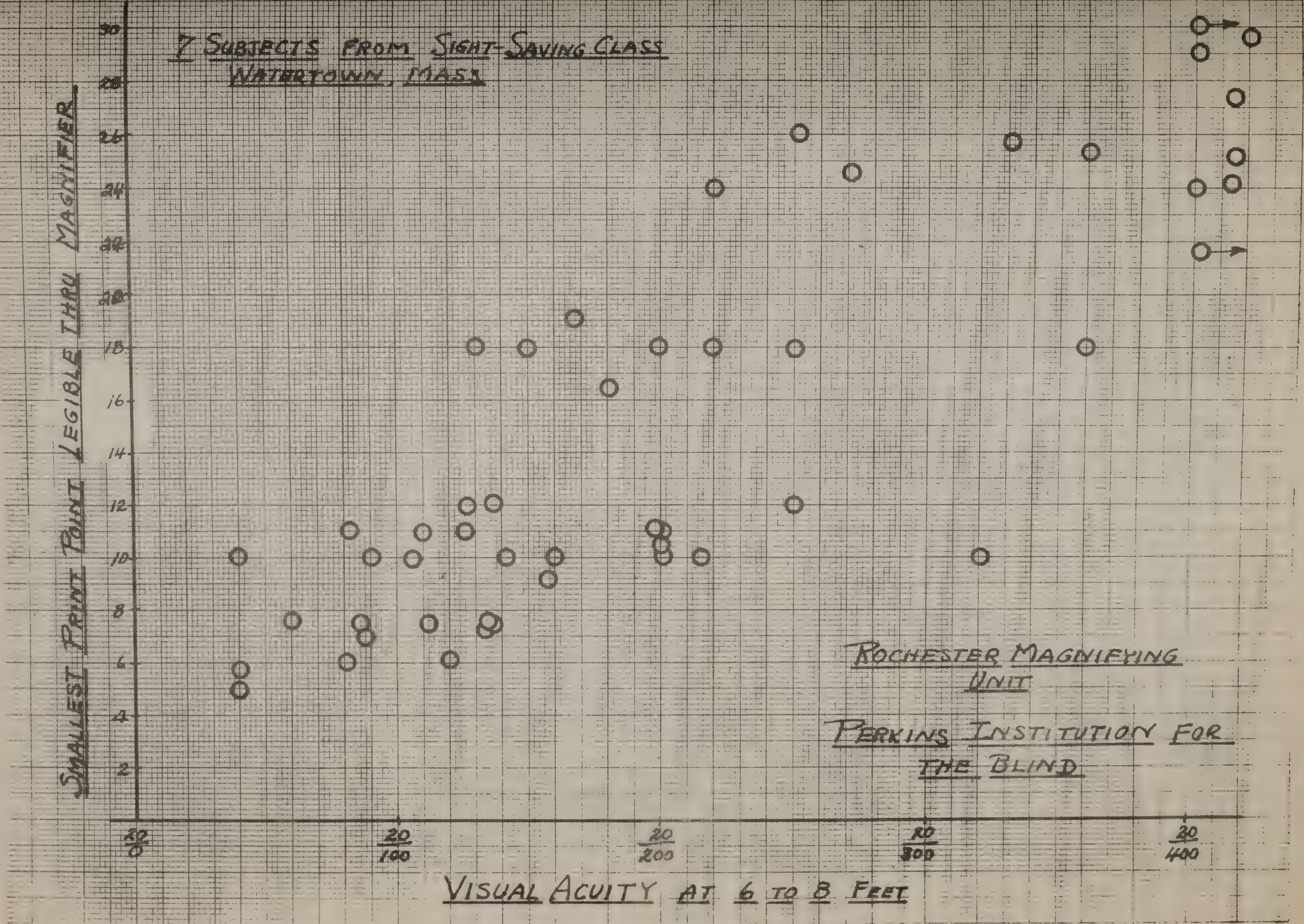


Figure 14. Scatter plot of data obtained on the large Rochester Experimental Magnifier.

prevented accurate refraction, a factor that must be taken into account. Some of the subjects were albinos who wanted less light on the test type. Many others wanted more illumination.

(5) Many students found it easier to read the test types at a distance of several inches from their eyes than to read it through the magnifier. This was evidence of too low a magnification.

(6) The data show that no subjects below 20/200 as measured in the usual manner, could read even 12 point type through the magnifier. Probably the magnifier, therefore, would be of little value for those with visual acuity below 20/150.

(7) Naturally the mounting of the instrument, its weight, and the difficulty of adjusting it to the print or book were criticized. All who made criticisms, however, tried to be encouraging.

Sight-Saving Class, Watertown, Mass.

In the sight-saving class in the Watertown Public Schools, seven subjects (the entire class), were also tested. The visual acuities were much higher here than those found at the Institution for the Blind, and the magnifier seemed to have greater potentialities in this group. Obviously, there are too few subjects here to draw conclusions. Their data have been included in the charts above.

The actual data taken at the Institution for the Blind and at Watertown are appended.

DATA ON TESTS

Perkins Institution for the Blind

Case No.	Initials	Visual Acuity at 8 to 10 ft. of eye tested	Smallest Print Point Legible through Magnifier	Comments
4*	M.M.	20/60	7-1/2	Albinism
5	F.G.	20/420	24	Aphakia, cong. cataract
6	J.J.	20/470	few in 24	High hyperopia
7	M.Mc.	20/200	10 slowly	Aphakia, cong. cataract
8	R.S.	20/400	24	High myopic astigmatism
9	G.P.	20/1000 (?)	18	Albinism, high myopic astigmatism
10	H.D.	?	few in 24	High hyperopic astigmatism
11	E.K.	?	few in 24	High myopic astigmatism
13	M.H.	20/320	10 slowly	High hyperopia
14	J.C.	20/200	18	Cong. cataract - aphakia
16	R.P.	20/135	7-1/2	Albinism, nystagmus
17	A.S.	20/363	few in 24	Cong. amblyopia, nystagmus, photophobia
18	E.B.	20/230	18 easily	Much light needed, aphakia, cong. cataract
19	H.S.	20/130	7-1/2	Albinism and nystagmus
20	J.C.	20/130	7-1/2	Magnifier no aid, high myopia
21	J.A.	20/210	10	Microphthalmus, amblyopia, cataracts, aphakia
23	M.D.	20/200	11	Ophthalmia neonatorum,nystagmus
24	H.S.	20/600	18 slowly	Optic atrophy,myopia,nystagmus
27	D.A.	20/250	18+	Cataracts
28	S.M.	20/110	11	Congenital amblyopia, nystagmus
29	E.D.	20/200	11 slowly	Coloboma of iris and choroid, nystagmus
30	M.H.	20/85	7-1/2	Likes magnifier, optic atrophy, nystagmus
31	T.B.	20/220	18	Cong. microphthalmus, aphakia, nystagmus
32	N.P.	20/1000	24 difficult	No record
33	M.S.	20/200	10	No record (visitor)
34	A.	20/166	18 slowly	No record - councilor
35	S.B.	20/400	24 poorly	Cong. amblyopia
36	A.F.	20/600	24 slowly	Buphthalmus
38	T.C.	20/360	24 poorly	Aphakia, cong. cataracts, nystagmus

*Numbers omitted indicate subject's visual acuity too poor to permit tests.

Case No.	Initials	Visual Acuity at 8 to 10 ft. of eye tested	Smallest Print Point Legible through Magnifier	Comments
39	J.E.	20/190	18 easily	No record - teacher
40	T.D.	20/250	few in 24	Albinism, third grade, perhaps doesn't know letters
41	R.H.	20/270	24 slowly	Microcornea
42	B.B.	20/133	11	No record
43	B.W.	20/450	24 poorly	No record,may not know letters
44	J.V.	20/220	24	No record, probably cannot read well
45	P.R.	20/100	10	Cong. cataracts
46	G.B.	20/125	12	No record
47	P. O'D.	20/250	12	No record
48	P.R.	20/1000	few of 24	No record
49	D.W.	20/150	18	Optic nerve atrophy, nystagmus
50	L.R.	20/230	18	No record
51	J.R.	20/323	less than 24	Secondary cataract, nystagmus
52	R.B.	20/88	7-1/2	Cataracts
53	T.L.	20/200	11	No record
54	L.T.	20/120	6	Bilateral adhesions, pemphigus
55	F.D.	20/160	9	Nystagmus
56	T.S.	20/110	7-1/2	Amblyopia, optic nerve atrophy
57	M.W.	20/160	10	No record

Sight-Saving Class, Watertown, Mass.

Case No.	Initials	Visual Acuity at 8 to 10 ft. of eye tested	Smallest Print Point Legible through Magnifier	Comments
58	K.D.	20/80	11	Nystagmus, astigmatism
59	W.C.	20/140	10	Amblyopia, squint
60	R.C.	20/40	6 too easily	High myopia, retinal changes
61	H.A.	20/40	6 too easily	Nystagmus, alternative converg. squint
62	P.B.	20/40	10-1/2	Choroiditis
63	R.B.	20/80	6 easily	Albinism, nystagmus, anisometropia
64	C.K.	20/135	12	No record

APPENDIX F

Functional Tests in Sight-Saving Classes in New York City on the Pilot Model Magnifier Using the Rochester Sphero-Aspheric Lens

Through the courtesy of the Board of Education of New York City, it was possible to test the magnifying device with the sphero-aspheric lens constructed by the University of Rochester, as mounted by the Dartmouth Eye Institute, in three of the public schools which conducted Sight-Saving Classes. Dr. Moses Freiberger, the school ophthalmologist, was present for the tests in the first school visited. The assistant to the Superintendent of the handicapped children in the New York Public Schools and the visiting teacher were also present for the testing.

The procedure was essentially the same as that at Watertown, Mass., vix.:

(1) To check medical record for visual acuity in each eye, and the causes of the subnormal vision, or the reason for each subject's being in the sight-saving classes.

(2) To determine the distance at which the subject held his school texts while reading.

(3) To measure the visual acuity at the near vision of 16", using Jaeger test chart.

(4) To check the smallest print that the subject could read through the magnifier.

(5) To note comments regarding practicability of the device.

In all thirty-five children of the seventh and eighth grades tested, of these:

26 were highly myopic or had high myopic astigmatism
1 was hyperopic
2 had nystagmus
1 had tunnel vision
2 had amblyopia ex anopsia
1 had congenital glaucoma
1 had albinism
1 had corrected aphakia

In general the children tested were of the underprivileged groups. At least half were Negroes. The majority were placed in the sight-saving classes because of high myopia, with the hope that the progression of the myopia might be reduced through the use of texts printed in large type (24 to 36 point), on the theory that large print at 14" produced less strain on those mechanisms involved

in progressive myopia than would regular print. It is questionable whether such groups provide the best test material in studying subnormal vision.

RESULTS

The data were plotted as in Appendix E, and these show that only those subjects with Jaeger 20/100 or better could obtain advantages with the use of the device. (See Figure 15) Because it was found that the visual acuities for distance which were recorded from the medical cards were unreliable, especially where so many of the subjects were myopic and probably undercorrected, the data were plotted against the visual acuity measured at 16". The proportionality should hold, however, and this method of plotting is justified with subjects in the age group tested.

A number of children found that with the device they could easily read texts (history) in ordinary type.

Among the supervisors of the sight-saving classes there were various opinions as to the usefulness of such a device. Most were encouraging and several would like to have a device in their classes to study. Several, however, saw no advantage at all, believing the solution to the problem was merely to print texts in large type.

The results were encouraging, but on the whole they suggest that the device as now constructed offers only the minimum in meeting the needs of subnormal vision.

The data follow :

TESTS IN NEW YORK PUBLIC SCHOOL SIGHT SAVING CLASSES

No.	Init	V. A. of Eye Tested Dist.	16"	Magnifier Print Point	Notes
3*	J.P.	20/70	20/60-	11	High (-12) myopia
4	E.K.	20/100	20/60-	10 - 11	Nystagmus, pathology
5	A.A.	20/100+		12 - 18	Amblyopia ex anopsia, hyperopia
6	F.M.	20/200	20/40	7-1/2	Myopic astigmatism
8	J.M.	20/100	20/35	6	High (-10) myopia
9	A.M.	20/200	20/80	11 - 12	Myopic astigmatism
11	I.H.	20/70	20/40	6 easily	Amblyopia ex anopsia
12	M.H.	20/70	20/40	6 readily	-6 myopia
13	E.M.	20/70	20/70	12	Optic nerve atrophy, tubular vision

*Those subjects whose visual acuity was found to be 20/20 or better were omitted in this tabulation.

No.	Init.	V. A. of Eye Tested Dist.	16"	Magnifier Print Point	Notes
14	G.S.	20/70	20/50	7-1/2	Nystagmus, high (-9) myopia
15	R.V.	20/100	20/30	6 readily	High (-13) myopia
16	A.V.	20/80	20/40	7-1/2	High (-10) myopia
17	J.G.		20/140	12	Choroiditis
18	H.D.	20/200	20/40	7-1/2	Nystagmus
19	L.P.	20/70	20/30	6	Corneal opacities, myopia, keratitis
20	T.A.	20/200	20/40	6	High (-12) myopia
21	M.R.	20/70	20/15	6 easily	High (-10) myopia
22	L.S.	20/70	20/60	12	Myopia, retinal changes
23	M.P.	20/100	20/100	18+	Myopia, nystagmus
24	P.L.	20/40 ?	20/100-	18	High (-16) myopia
25	B.D.	20/70	20/15	6	High (-13) myopia
26	M.G.	20/40	20/25	6 easily	Myopia (-6)
27	J.H.	20/70	20/60	11	Albinism
27	J.H.	20/100	20/80	12 - 18	Albinism
28	E.R.	20/70	20/20	6 easily	Myopia
29	A.O.	20/100	20/100	18 poorly	High (-10) myopia
30	M.C.	20/100	20/40	6	Myopia (-7)
31	F.M.	20/60	20/30	6	High (-12) myopia
33	R.R.	20/100	20/100	10 - 11	Myopia (-6.50)
34	V.W.	20/70	20/60	6	Myopia (-7)
35	C.W.	20/200	20/100	12 - 18	Aphakia
35	C.W.	20/200	20/70	10	Aphakia

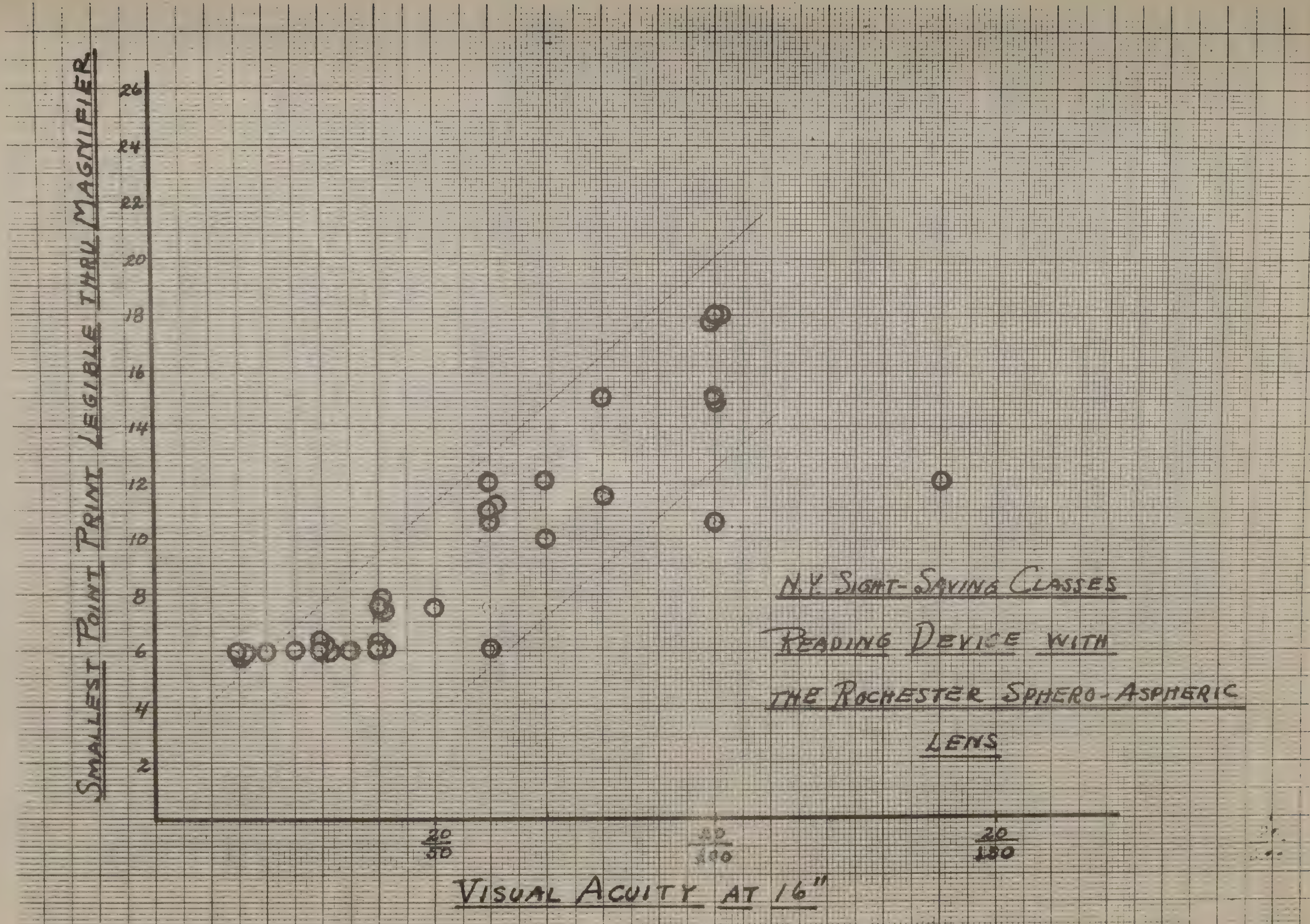


Figure 15. Scatter plot of data obtained in sight-saving classes with pilot model device with sphero-aspheric lens.

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